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SMITHSONIAN INSTITUTION
ASTROPHYSICAL OBSERVATORY,

(NASA CR 51375)

2. OPTICAL SATELLITE TRACKING PROGRAM

Carried out under a grant

from the

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

(NASA Grant No. G 87-60)

3. Semi-annual Progress Report No. 2, Jan. - June 30, 1960

CAMBRIDGE 38, MASSACHUSETTS

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Semi-annual Progress Report No. 2

January through June 30, 1960

Project Director: Fred L. Whipple

October 7, 1960

Cambridge 38, Massachusetts

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I. PHOTOGRAPHIC TRACKING STATIONS

Prepared by: Edward H. Shenton
John J. Grady

1. Progress During This Period

The Baker-Nunn stations successfully photographed 550 satellite passages in December, 1959. Since then, the work load has increased steadily, as shown by the station output of more than 1300 successful photographs in May, 1960. The December figure represented 30 percent of the predictions sent to the field; the May figure, more than 40 percent.

Some progress has been made in improving the quality of long-range photography, particularly by the station staffs at Spain, Curacao, and New Mexico. We expect that these efforts, with collaborative work by Computations, will result in a considerable improvement in record quality toward the end of 1960.

A. Cooperative Agreements for Station Operation

The following list shows the status of our agreements as of June 30, 1960:

Argentina: The agreement of October 23, 1959 with the University of Cordoba, for the lease of land, was extended through June 30, 1961. Negotiations are continuing for a country-to-country agreement for the operation of the tracking station.

Australia: A revised draft of an agreement between NASA and the Department of Supply, Commonwealth of Australia, was drawn up with the concurrence of Smithsonian Institution and submitted for signatures to the Department of Supply.

Curacao: The lease on the property of Mijin Maatschappij was extended to June 31, 1961.

India: The original informal letter of agreement, dated February 26, 1958, between Dr. Whipple and Dr. Mitra, Secretary, INCIGY, continues in effect.

Iran: A country-to-country agreement is under negotiation.

Japan: A new agreement is to be drafted.

Peru: Mr. Kenneth Drummond negotiated a contract with the Instituto Geofisico de Hunacayo for the lease of the land and for the operation of the station through June 30, 1961; the contract now awaits signature.

South Africa: The government-to-government agreement is under negotiation by the Department of State on behalf of NASA.

Spain: The informal agreement of August 14, 1959 continues in effect.

B. Observing Techniques

We had demonstrated earlier that the Baker-Nunn camera could photograph small satellites at ranges of several thousand miles. However, records obtained at extreme range are generally not satisfactory for precise reduction because their quality and their quantity are restricted by imperfect matching of the camera path to the satellite path.

While tracking a satellite across the entire North American continent, both the Florida and the New Mexico stations achieved simultaneous photographic records for 12 minutes.

The San Fernando station photographed a satellite about 50 degrees distant (3500 miles).

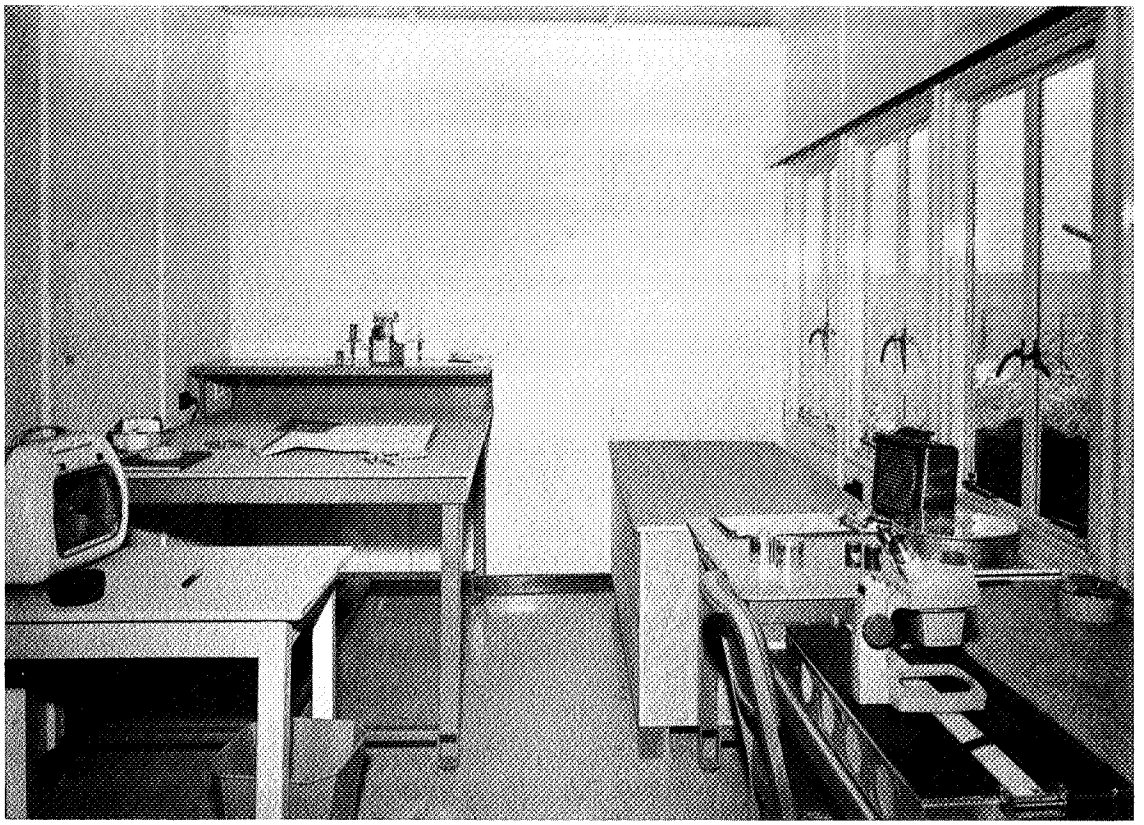
These test achievements indicate that direct triangulation over very long arcs is practical. The San Fernando station made a significant technical advance by developing a simple camera modification that enables the observer to take long-exposure identification photographs without interrupting the basic exposure sequence of the camera. This technique will be very valuable when we progress to simultaneous operation by several stations. The Shiraz camera has also been modified so that the station can participate in synchronized triangulation operations.

Fully utilizing the data supplied by means of these techniques, which until now have been experimental, Computations will be able to provide high-quality predictions to the stations for long-range observations in the next six months.

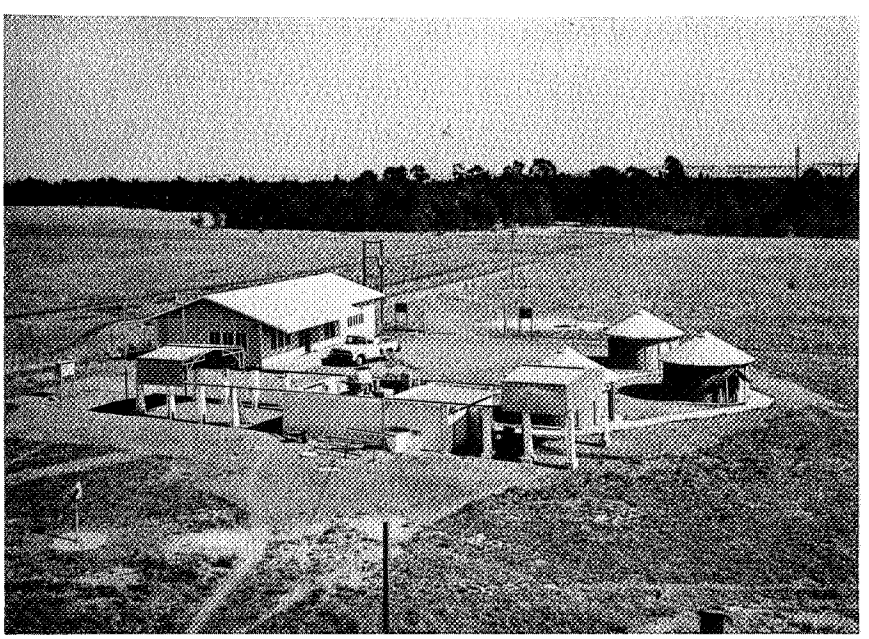
C. Improvement of Records

We have continued the policy of sending Photoreduction assessments of individual records to the stations. We now issue the data on IBM printout sheets, thus minimizing delays and personal effort. A number of stations contributed ideas toward the design of a new multi-part camera log sheet to further improve the exchange of assessment data. On August 1, 1960, we will begin to use this form, which incorporates suggestions from Photoreduction.

The production of hundreds of thousands of photographic records for precise metric reduction has posed a number of problems in controlling the quality. A preliminary formulation of record standards in terms of information content, readability as related to record production, and handling, has resulted in the development of a semiquantitative code for describing faults and defects in the records. This code is used to communicate these faults to Photoreduction and to provide a framework for the discussion of improvements in operational techniques throughout the system.



Film reduction room, South Africa station



Air view of South Africa station

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D. Improved Photographic Techniques

Some 20 percent of records suitable for field reduction are now unsuitable for precise reduction because of unsatisfactory photographic processing. We have therefore begun a major program to control the quality of the photographic records.

We are developing methods to control the processing to yield optimum speed and contrast under the vast range of exposure conditions, in which the brightness of twilight sky may vary in the order of a million to one. To maintain this control we will supply densitometers and sensitometers to field stations for routine checks on the quality of films and chemicals.

As a part of the attempt to control exposure, we made a preliminary investigation of the magnitude limits the Baker-Nunn camera can record under bright sky conditions, to aid in the design of observing programs for project Echo. We are continuing to analyze the results of field photography. Generally, we can obtain barely useful records within 10 minutes of sunrise or sunset.

E. Observer Training Program

The training program, which includes a meeting at Cambridge followed by a brief training period at a field station, was continued. During this report period, observer trainees were sent to Jupiter, Florida, for the second phase of their training.

We initiated a new training session for electronics personnel. Three observers and one staff member spent a week at the Norrman Laboratories, Williams Bay, Wisconsin, for advanced training on the operation and maintenance of the Norrman Time Standards. We will later offer additional sessions for observers with advanced electronic skills.

2. Operations

The following list tabulates the successful satellite observations made by individual stations for the period January 1 through June 30, 1960:

Station	Number of Successful Observations
Argentina	460
Australia	719
Curacao	403
Florida	434
Hawaii	571
India	306
Iran	348
Japan	361
New Mexico	481
Peru	427
South Africa	550
Spain	580
Total	5640

Field Reduction

Satellite 1960 Delta (Discoverer XI) carried incandescent lamps programmed to turn on in the vicinity of each of four of the Baker-Nunn stations. Bad weather prevented observations by three stations, but the San Fernando station obtained 15 successful photographs that were reduced with all possible care at the station, and gave an accuracy of about 1 minute of arc. This figure, which represents a considerable improvement on the accuracy of 2 to 3 minutes of arc usually obtained in field reduction, has given us confidence in our tentative plans to introduce measuring techniques in the field that would give quick reductions accurate to about 30 seconds of arc.

Such an accuracy would be significant in several areas. Most important, it would make much improved data immediately available to the Research and Analysis staff. Since precise reductions at Cambridge necessarily involve delays of many weeks, the significance of the improvement is evident. Also, such an accuracy in the reduction of each observation will enable us to improve the predictions of satellite passage. Therefore, we may either increase the precision of predictions with the present number of observations or work

toward producing useful predictions from a reduced number of observations. The latter system could be important if the Baker-Nunn network were asked to observe a very large number of satellites on a routine basis. We are still considering the most effective way to utilize the potential accuracy of the records with limited field effort, and to make use of the automatic facilities at Cambridge. For example, the SAO star catalogue can obviously be used to diminish greatly the field effort involved in reduction. The Computations Division would then have only the task of reducing individual reference stars and interpreting satellite positions.

3. Equipment and Instrumentation

Basic equipment in use at the stations operated satisfactorily. Routine mechanical and electronic maintenance continued.

A. Mechanics and Optics of Camera

The new desiccation system, designed to prevent the formation of moisture within the corrector cell, has been installed at the New Mexico and Florida stations. The unit has been performing properly, and additional ones are now en route to Spain, Curacao, and Japan.

The shutter calibration device described in Progress Report No. 1 has been successfully installed at the stations in New Mexico, Florida, Spain and Curacao. It has performed well and appears to give the required positive calibration of the camera shutter. Using this calibrator as a standard, we will make further tests to compare the former method and the new one.

The Engineering group has continued its experimental and developmental program. They have proposed several mechanical improvements to solve a number of operational difficulties; among the proposals are a magazine reel brake, a modification of the film transport system, and an all-mechanical slave clock.

No further work was done on the new back-up plate for the camera because of other, more pressing problems.

An additional corrector cell, No. 13, completed by Perkin-Elmer Corp. and accepted by us in May, 1960, is believed to be, in terms of resolution and image quality, the best that Perkin-Elmer has manufactured for us. The cell was installed in the camera at Organ Pass, New Mexico, in May. The cell it replaced was returned to the factory for inspection and any reworking necessary to bring it to the quality of No. 13.

A modified film drier, similar to that under test in Hawaii during the last report period, was constructed and sent to Florida. The station reported that, although the drier eliminated dust and dirt, it nearly doubled the drying time. Further testing of this and other commercial driers is obviously required.

B. Timing System

Further work was done to improve the operation and results of the Norrman time standard.

We procured and installed the inverter power supplies in four stations. While this is a definite improvement, in that the stations are no longer dependent on unregulated commercial power alone, this power supply may need further modification and engineering before it becomes completely satisfactory.

Several stations have been able to provide a more suitable environment for the time standard by providing additional space with air conditioning, to ensure constant temperature and some moisture control.

We have issued forms to all stations for the weekly report of malfunctions in the timing system.

We are attempting to obtain a timing system with the required accuracy of 1 millisecond. This has been proved impossible with our present equipment, which utilizes high-frequency signals and therefore has a limit of accuracy of several milliseconds. With recent advances, timing systems now take advantage of low-frequency signals coupled with stable oscillators to produce an accuracy better than 1 millisecond. We issued invitations to bid on a prototype time standard to several firms, and placed the contract with Instrument Corporation of Florida, a firm widely experienced with the precise timing of photographic records and the integration of timing systems in the field of ballistic missiles. Delivery is expected in the second half of 1960. This prototype will be used experimentally and tested in various locations. Additional laboratory equipment was purchased to establish basic test facilities for the new timing system. The Engineering Support Group is developing an electronics laboratory to aid in the proper evaluation of the prototype timing system.

4. Logistics

We continued to supply stock items to all 12 stations. Serious delays were encountered in clearing goods through the Argentina customs. With the negotiation of an agreement with Argentina and the U. S. Embassy, we hope to be able to arrange and handle quickly the entrance of station supplies into that country. At the India Station we have had similar difficulties in rapidly processing duty-free entry for supplies.

Each station made a survey of its film storage space, to determine maximum capacity for both emulsion types. We have tried to provide at least six-months supply to stations with unlimited cold-storage capacity.

All stations overseas received large shipments of stock supplies by sea freight, except Iran, to which sea shipments are sent by commercial air freight. During this period approximately 15 tons of supplies and equipment were shipped by sea, and about 1 ton by air freight.

Additions to Station Buildings

The new administration building in South Africa and the addition to the Argentina camera house were completed during this period. The construction of a larger administration and film reducing area in Argentina progressed. We completed the housing for a 40 kw standby generator, except for final wiring.

The station in Peru made preliminary arrangements for increasing the local water supply and for providing a greater amount of regulated commercial and standby power.

Plans for additions to the camera houses in Curacao and Florida are well along. Since similar additions are scheduled for several other stations, we have drawn up a building code to provide uniform specifications within the limits of variations in overseas environments and conditions. As soon as these specifications are included in bids for construction at the proposed stations, we shall proceed with the construction of additions at Curacao and Florida.

5. Personnel

Listed below are the visits made by Cambridge personnel to the field stations.

Dr. Fred L. Whipple visited the stations in Argentina, Peru and Curacao for scientific and administrative purposes during the month of March.

Mr. Kenneth H. Drummond travelled to the stations in Peru and Curacao in the month of June for the renewal of agreements.

Col. Olcott M. Brown, late in December and January, visited Iran to do preliminary work on a country-to-country agreement, and discussed with the Iranian scholars at the University of Teheran a proposed agreement with Smithsonian concerning the operation of the tracking station at Shiraz. He made a short stop to inspect the San Fernando Station. In May, he visited the Hawaii station and the University of Hawaii, and in June the New Mexico Station.

Mr. John Grady accompanied Col. Brown to introduce and train personnel at the Iran and Spain stations in the new methods and procedures of satellite tracking, as well as in certain methods in field reduction of photographs. In late January, Mr. Grady and Mr. Edward Shenton visited the stations in Peru, Argentina, Curacao, and Florida, to introduce new techniques; and at the Minitrack Stations in Lima, Peru, and Fort Meyers, Florida, they consulted with their personnel on Minitrack methods of satellite observations. In March, Mr. Grady made a similar trip to the New Mexico Station, and in late June, he inspected the U. S. Air Force installation (Spacetrack) and consulted with the officials at Fairbanks, Alaska.

Mr. Edward H. Shenton inspected the Peru and Argentina stations; while there he did preparatory work on country and agency agreements for Smithsonian. He also stopped briefly at Curacao and Florida.

Mr. Jack Slowey visited Curacao and Florida to familiarize himself with the station.

Mr. Aubrey Stinnett in January visited the Florida station to develop a new shutter calibration method. He went to the San Fernando station during March to perform camera maintenance; and in May he installed and tested equipment at the New Mexico station.

Mr. Edwin Jeffrey visited the Florida station in January, the San Fernando station in March, and the New Mexico station in May, to assist Mr. Stinnett in the installation and test of new equipment. In June he remained at the Shiraz Station in Iran to perform necessary maintenance on the camera.

Mr. Carl Hagge accompanied Mr. Grady and Mr. Shenton to the Argentina, Peru, and Curacao stations in January to perform urgent repair on the Norrman clock, power amplifier, and electrical system. In April he visited Florida to install and test the clock power supply system.

Mr. Stephen Sydor visited the San Fernando station in Spain during the month of March to clean and adjust the camera optics.

Six new observers, selected from 55 candidates, were hired for the Satellite Tracking Program and were assigned to stations.

During this period several experienced field observers returned for assignment to Cambridge headquarters; members of the Cambridge Staff took over their former positions.

6. Publications

Nineteen technical memos were issued during this period.

	1. Observing Techniques	Date Issued	Written by
1-9	Camera logs 'power amplifier' entry	5/20/60	Grady
	2. Camera Operation, Adjustment, etc.		
2-14	Simplified camera focus procedure	4/15/60	Stinnett
2-15	Camera vibration	4/14/60	Stinnett
2-16	Installation of shutter calibrator	4/28/60	Jeffrey
2-18	Electrical connection of shutter calibrator	5/6/60	Hagge

3. Time; Clock Operation

3-7 Installation of mini-box assemblies	1/28/60	Hagge
3-8 Clock log	2/3/60	Hagge
3-9 Clock log supplement	2/9/60	Hagge
3-10 Auxiliary extension cables	4/18/60	Hagge

4. Photography and Film

4-6 Film blemishes	1/22/60	Stinnett
4-7 Unsuccessful records	4/22/60	Grady

5. Power Supply

5-1 Rotary converter power supply: description and operating procedures	4/14/60	Jeffrey
5-2 Rotary converter power supply: installation	4/14/60	Jeffrey
5-3 Maintenance of battery bank	5/ /60	Jeffrey

6. Communications

6-13 Launch code 111	1/13/60	Grady
6-14 Abbreviation of long-arc observation on code 222 messages	3/18/60	Shenton
6-15 Revised communications format for transmission of Baker-Nunn observations	4/15/60	Peterson

7. Miscellaneous Technical Matters

7-4 Observing summaries	5/2/60	Grady
7-5 Baker-Nunn drive test	5/24/60	Grady

7. Future Plans

In the coming months, we plan the following projects:

1) Install shutter calibrators, high-capacity desiccators, and inverter clock power supplies at stations where they are needed.

2) Further modify the film drier after we have made a more thorough survey and if evidence still warrants its use.

3) Continue our evaluation of Royal X-pan film.

4) Do further work on additions to the camera houses that were begun during this period.

5) Cooperate in the production of the new time standard, and after experimental studies, field test it as a prototype for use at all stations.

6) Evaluate sensometric equipment; the results obtained will be used to achieve higher quality photographs for further reduction.

7) Continue experimental and developmental work to improve the capabilities and uses of the tracking cameras and associated equipment.

II. VISUAL OBSERVING PROGRAM

Prepared by: Leon Campbell, Jr.

1. Progress During This Period

Leaders of twelve Moonwatch teams attended a conference at the Observatory on June 18 and 19. With members of the staff they discussed ways and means of obtaining more accurate observations. Their conclusions will be published in Moonwatch Bulletin No. 12, dated August, 1960.

Six new teams have affiliated with the Program; their stations are at Calgary, Canada; Toronto, Canada; Lisbon, Portugal; Galena, Alaska; Evanston, Illinois; and Madison, Wisconsin.

We have made an effort to limit the stations to those making a positive contribution to the Program. As a consequence, 72 stations were withdrawn. The Program continues, as of June 30, 1960, with a total of 137 affiliated teams.

In addition to regular tracking, selected Moonwatch teams took part in the following special projects:

Alert to Observe Lighted Satellite. In January a group of teams in the United States, Australia, and Great Britain was alerted to observe the lighted Discoverer satellite, 1960 Delta, scheduled for launching during the month. Because of postponements of the launching, teams were kept on alert through April 15, when Discoverer XI was launched. In every area where Moonwatch teams were cooperating with the Baker-Nunn stations, poor weather conditions prevented observations. (Only the tracking station in Spain photographed the lighted satellite; there are no Moonwatch participants in that country.)

Alert for Project Echo. Approximately 60 Moonwatch teams widely distributed geographically were alerted for Project Echo during the month of May, but the satellite did not go into orbit.

Decay of Satellite 1958 δ2. The Moonwatch network was alerted to observe the demise of Satellite 1958 δ2. The demise occurred on April 6, 1960. The final alert predicted the decay would take place between 0700 and 1900 UT on that date. Indications are that decay occurred early in this period over the middle or south Atlantic and out of range of the Moonwatch teams.

Satellite 1960 γ2 Project. During May the network participated in a concentrated program of observing Satellite 1960 γ2; the purpose of the assignment was to measure the ability of individual stations to make accurate observations.

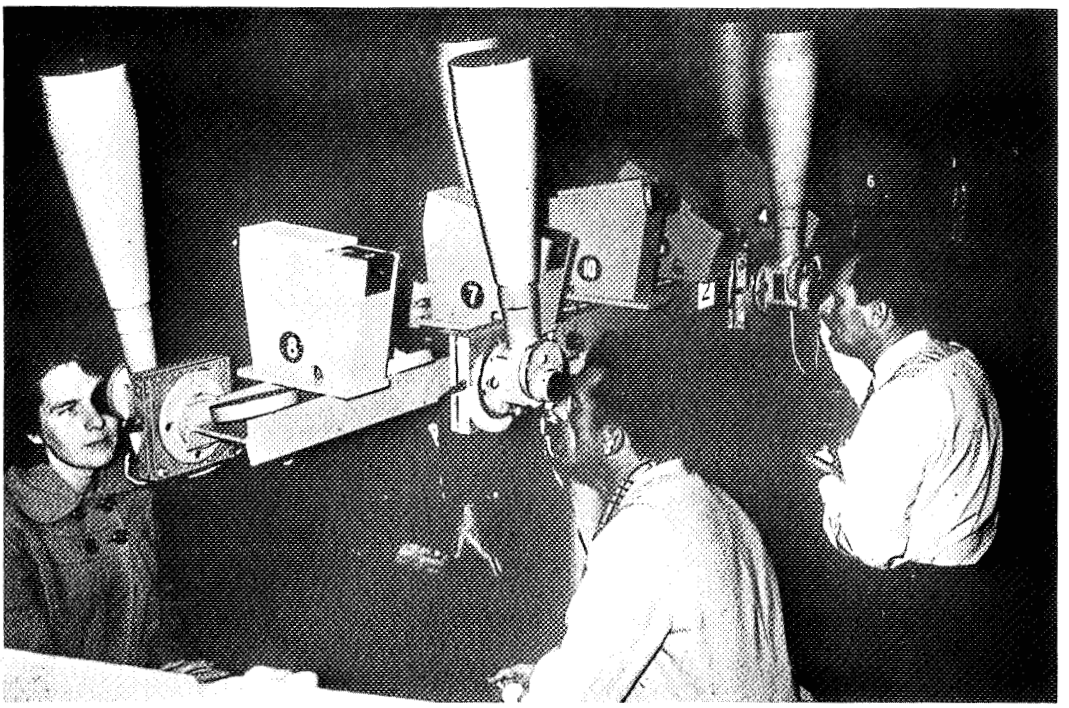
Observations of Satellites 1960 ε1 and ε2. Immediately following launching of Satellites 1960 ε1 and ε2 on May 15, six U. S. stations were alerted to acquire them. The stations reported several observations during the first day of orbiting, and from these and other data, orbital predictions were derived at the S. A. O. Four days after launching, the Rochester, N.Y., Moonwatch team observed five objects resulting from the separation of the ''chamber'' from the ε1 object. These observations and those of two additional components were verified by other teams, thus confirming the total number of 1960 Epsilon components as nine. Thereafter, Moonwatch teams participated in a special project providing observational data on 1960 ε3 through ε9.

Operation 2260 (Satellite 1960 Eta). Eight Moonwatch stations were alerted to obtain observations of the objects on their first North-South pass over this country. The teams were given prelaunch data through the use of Code IX, which was necessary because one of the satellites (1960 η1, Transmit IIA) was classified. No observations were obtained of the first revolution, but within two days observations began coming from other teams of the network.

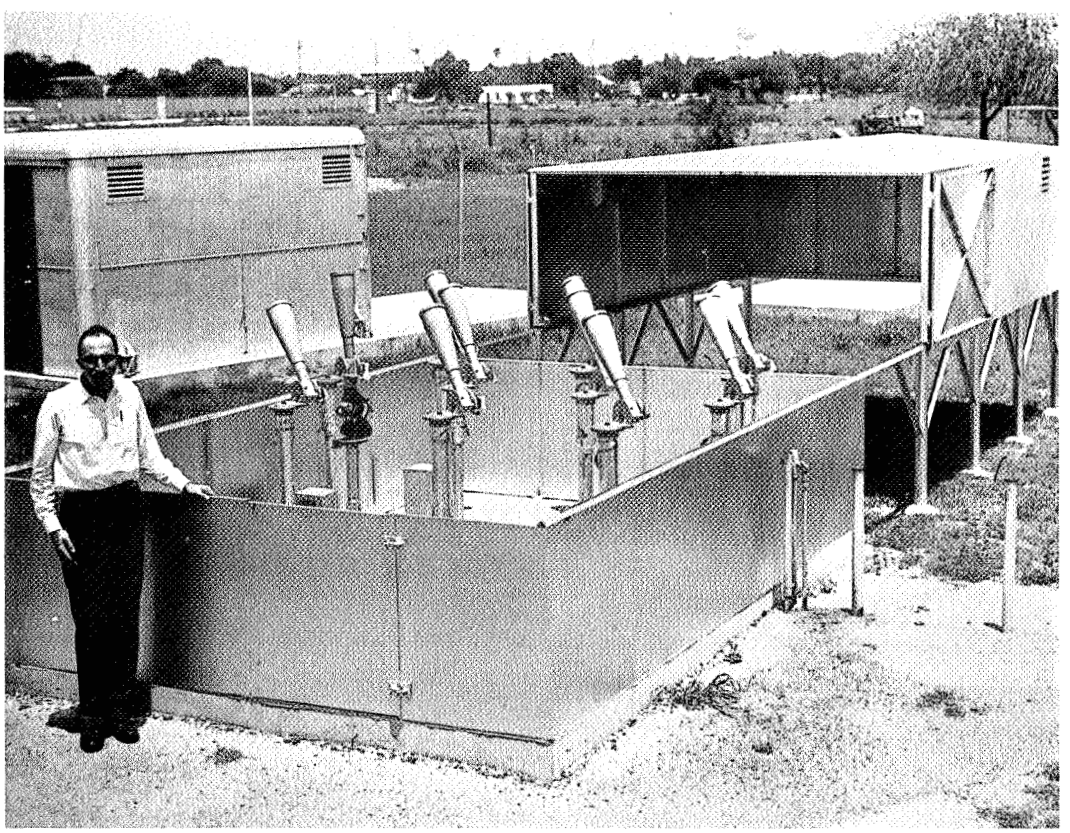
2. Operations

During this six-month period, Moonwatch headquarters received a total of ~~4095~~ 4126 observations, as follows:

Satellite	No. of Observations Received	Satellite	No. of Observations Received
1958 Alpha	197	1959 Lambda	72
1958 β1	184	1960 β1	312
1958 β2	6	1960 β2	248
1958 δ2	214	1960 γ1	248
1959 α1	239	1960 γ2	298
1959 α2	396	1960 Delta	1
1959 δ1	4	1960 ε1	206
1959 δ2	13	1960 ε2, etc.	339
1959 ε2	91	1960 ζ1	121
1959 Eta	331	1960 ζ2	41
1959 ι1	436	1960 η1	27
1959 ι2	23	1960 η2 and η3	79
		Total	4126



Moonwatch team in Perth, Australia, using apogee telescopes



Installation of Moonwatch team in Edinburg, Texas

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The following list provides the total number of observations received since the beginning of the Moonwatch program:

Period	No. of Observations Received
Second Quarter 1960	3099
First Quarter 1960	1027
Fourth Quarter 1959	1297
Third Quarter 1959	1128
Second Quarter 1959	900
First Quarter 1959	625
Fourth Quarter 1958	1347
Third Quarter 1958	2867
Second Quarter 1958	747
First Quarter 1958	1490
Fourth Quarter 1957	1856
Total	16,383

3. Equipment and Instrumentation

The Moonwatch project purchased a four-inch photographic equatorial telescope with an astrocamera, and a photometer for scientific experiments to be conducted by Dr. Gustav A. Bakos. The instrumentation will be used to obtain daylight observations of stars. The position and magnitude corrections that are determined will be used for further experimentation relating to satellites.

We also purchased a chart recorder to be used with the satellite simulator, which is being modified for use in determining the personal equation of each observer. The chart recorder will permit a clearer analysis of the reaction times of different individuals in observing a simulated satellite crossing. This study is part of a program to secure more accurate timing of observations.

4. Logistics

During this period, 27 apogee telescopes were completed by the Naval Weapons Establishment and distributed to three Prime stations. Eighteen stations have been shipped a total of 149 M-17 elbow telescopes, and three stations have received tape recorders.

5. Personnel

Mr. Leon Campbell, Jr., Chief Moonwatch Project, in March attended the orientation conference of Project Echo held by NASA in Washington, D. C. In April he conferred with the Supply Division at Smithsonian Institution and discussed equipment for the Moonwatch Program.

Dr. Gustav A. Bakos, Astronomer, in January visited members of the Royal Astronomical Society in Toronto, Canada, to discuss the organizing of Moonwatch teams in Canada. In March he confered with Dr. Van Biesbroeck at Yerkes Observatory in Williams Bay, Wisconsin, and visited Moonwatch teams in Milwaukee, Wisconsin, North Canton, Ohio, and Pittsburgh, Pennsylvania. In April, he read a paper on observing satellites with simple instruments at the General Assembly of the Royal Astronomical Society in Montreal; he also travelled to Ottawa to organize new Moonwatch teams, and to Rochester, N. Y., to visit the station there. In June, with Mr. Stefan Sydor, he went to Ocean Springs, Miss., as a consultant for the Celescope Program and to Biloxi, Miss., and New Orleans, La., to visit the three teams there. At the end of June he travelled to Toronto to consult with Royal Astronomical Society officials and to make scientific studies at David Dunlap Observatory.

Mr. Aleksander Bilinski, Field Representative, accompanied Dr. Bakos on his inspection of Moonwatch stations at Milwaukee, Wisconsin; North Canton, Ohio; and Pittsburgh, Pennsylvania.

In June Mr. Edward H. Kohn, Station Coordinator, surveyed station operations in State College and Pittsburgh, Pennsylvania.

The following persons joined our staff:

Mr. Hebert C. Doughty, Computer, on 2/21/60;

Mr. Edward H. Kohn, Station Coordinator, on 5/2/60;

Mr. Robert W. Martin, Computer, on 6/13/60; Mr. Martin had left the Program to return to Rensselaer Polytechnic Institute on a full scholarship on 1/29/60.

Mr. Philip W. Levin, Station Coordinator, left the program on 4/29/60.

6. Publications

During this period we prepared and mailed to the stations the following publications: twelve Newsletters; Special Bulletins Nos. 37-47; and Observing Status Lists Nos. 22-33.

7. Future Plans

Future plans include:

1) A concentrated effort to achieve greater accuracy in measuring the times and positions of observations;

2) The securing of light-curve measures of satellites from a selected number of stations;

3) Further consolidation of the network so that it will include only productive teams;

4) Organization of teams in geographical areas not yet covered, particularly in the higher latitudes.

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III. COMPUTATIONS DIVISION
and
RESEARCH AND ANALYSIS DIVISION

Prepared by: D. V. Mechau

1. Progress During This Period

Work has continued on several large-scale computer programs and on a number of projects in research and analysis.

A. Computations

Because of the nature of the problems and the complexity of the computations, some of the computer programs reached a partial operating stage while not yet being completed or refined.

Of the new SATELLITE PREDICTIONS PROGRAM for the SAO Baker-Nunn camera stations, the first part has been completely checked out and found to be operational. The second part is now being coded and should be completed before the end of the year. This predictions program will supersede most of our special programs that have been in operation for some time. It is a multipurpose program devised to produce the appropriate type of predictions for a given situation. It will handle satellite orbits of all types, as well as space probes. Flexible in all its operational aspects, it will increase efficiency in all phases of prediction, communication, and tracking. Through this program we can expect to achieve a greater accuracy of observations and a consequent increase in the number of films suitable for fine reduction.

The SAO DIFFERENTIAL ORBIT IMPROVEMENT PROGRAM (DOI) has continued to undergo refinement and expansion. The input format for several programs has been altered in such a way as to provide direct use of the refined orbital elements that form the output of the DOI program. Great efficiency has thereby been gained in operating the computer and in saving the time of scientific personnel.

The AUTOMATIC REDUCTION PROGRAM for the processing of Baker-Nunn camera photographs has been improved by changing the form of the output. We have prepared flow charts on the new program for both the IBM-704 and the IBM-7090, and made preparations to use the final form of the SAO Star Catalogue with the Automatic Reduction Program.

The SAO STAR CATALOGUE continues to progress. The purpose of the project is to establish a uniform catalogue of mean positions and proper motions of stars throughout the entire sky. Our aim is to have at least three or four stars per square degree, with a mean positional error of not

more than one second. The catalogue will be primarily used to reduce manual labor and to provide a quick, efficient method of identifying stars in the Automatic Reduction Program. Of course, the project will provide us with a library of different catalogues on punched cards and tape and thus will greatly simplify stellar work of a statistical nature.

In order to cover the entire sky, we are using 11 different catalogues totaling 50 volumes; 500,000 cards will need to be processed. Each star is reduced to refer to the equinox of 1950, then reduced to a common format, and finally reduced to a well-defined fundamental system; this procedure eliminates the systematic errors of each individual volume. Each star is then sorted with all other stars, and compared with those nearby to see if it has occurred in any other catalogue. If it has not, it is ready for the final sort. If it has occurred in other catalogues, then all positions for this star are used to compute the proper motion and mean position. Our final catalogue will contain approximately 250,000 stars.

Thus far all stars have been punched on cards, prepared for taping, and loaded on tapes. Cards with different types of data for the same star have been merged onto single cards or card images on tape. The stars of one of the catalogues have been reduced to a common equinox, format, and system.

Programming of various shorter routines was completed; among these routines might be mentioned:

1) Improvement of the Lunar Probe Program.

2) Additions to the SAO Ephemeris Zero Program for the computation of satellite velocity and geomagnetic field to accompany the position at any given moment. (Values for the total magnetic field and dip angle can also be obtained.)

3) Modification and improvement of the existing program for fitting least-squares curves.

4) A maintenance program for files of satellite observations.

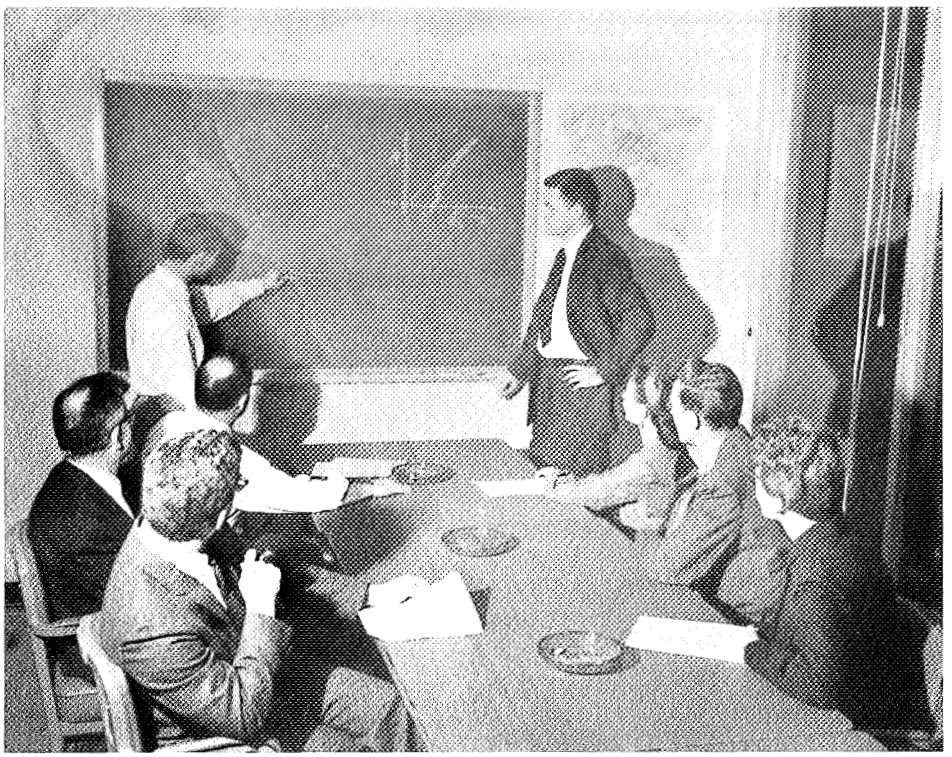
Two programming projects are underway:

1) Selection of utility program systems for the IBM-7090.

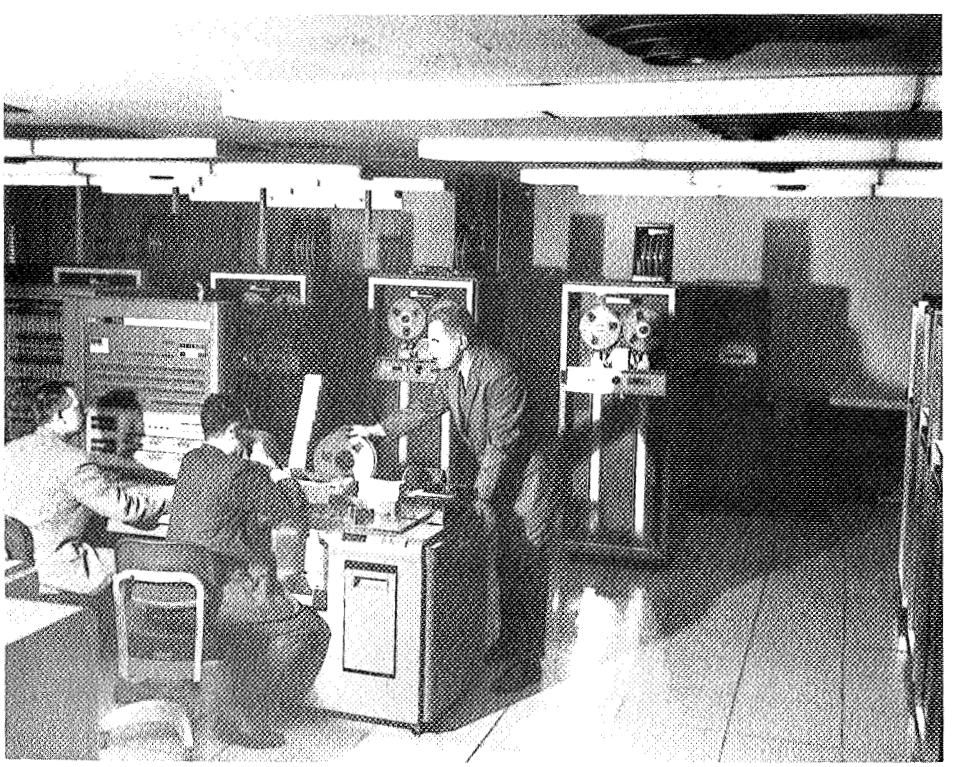
2) Modifications of existing SAO programs for use on the IBM-7090.

B. Research and Analysis

Members of Research and Analysis continued their studies of the earth's gravitational field and of the upper atmosphere.



A conference in computations section



IBM-704 electronic computer

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The derivation of the earth's potential from the motion of the artificial satellite is one of the most interesting problems in the satellite research project. Y. Kozai has now derived more accurate values of the second, third, fourth, and fifth harmonics of the earth potential by analyzing the motions of Satellites 1958 β2, 1959 Eta, and 1959 ι1. His results will appear in the Astronomical Journal.

If the orbital inclination of an artificial earth satellite is very near the critical value (about 63°.4, the secular motion of the argument of perigee is very small. When the usual method of approximation is employed, a very small divisor appears in the expressions of the long-periodic variations of the orbital elements. To avoid this difficulty, Drs. Y. Hagihara and Kozai applied to the problem a theory similar to that of the libration of asteroids. In their study, not only are the second and fourth harmonics of the earth potential taken into account, but also the third harmonic is included. Explicit expressions for all the elements are given. This paper, as well as one by Dr. Kozai entitled "The Effect of Precession and Nutation on Orbital Elements of a Close Earth Satellite," will also be published in the Astronomical Journal.

A remarkably close approximation to the actual gravitational field of the earth was discovered by J. P. Vinti of the National Bureau of Standards. This approximation makes possible the construction of an analytical theory for the motion of an artificial satellite that would surpass the accuracy of theories now available. Mr. I. G. Izsak undertook a detailed study of the integration of Vinti's equation to obtain explicit formulas well suited for numerical computations.

The most important air-drag perturbation upon the motion of an artificial satellite is the secular decrease of the semimajor axis and of the eccentricity. In the case of low orbiting satellites, the periodic-drag perturbations also become significant. Mr. Izsak investigated the possibility of an analytical representation of these variations in the orbital elements, and derived Fourier series expressing the relevant elements as functions of the eccentric anomaly. He presented his results at the Pittsburgh AAS meeting in April. C. H. Moore has programmed the equations for computations on the IBM-704. Mr. Izsak has prepared a paper on this subject for the Astronomical Journal.

Dr. Kozai has prepared a paper "The Effect of Precession and Nutation on Orbital Elements of a Close Earth Satellite," in which the perturbations due to the motion of the equatorial plane of the earth are derived for the orbital elements of a close earth satellite. He has submitted it to the Astronomical Journal.

Dr. P. E. Zadunaisky has analyzed the orbital elements and secular accelerations of several satellites in order to determine the atmospheric densities and the coefficients of the effective variable-drag area of a nonspherical satellite.

Dr. C. A. Whitney has made preliminary studies of the thermodynamics of the diurnal behavior of the atmosphere. This work was directed toward

interpreting the Jacchia variable-density model of the atmosphere. A simplified treatment indicates that the Jacchia model is consistent with expected ionosphere motions produced by the heating of the upper E layer. A more elaborate study is now in progress.

With the assistance of Mrs. G. D. Johnson, Dr. Whitney has undertaken a study of the radiative transfer of the 63μ radiation of atomic oxygen. The purpose of this study is to test the possibility of using rocket experiments to provide data concerning the E and F layers of the atmosphere.

Mrs. Johnson concluded her work on the analytical solution of the time-independent heat equation for heat conduction in a plane parallel atmosphere with prescribed boundary conditions. Using data from Nicolet, she also completed a program for the numerical solution to the problem of radiation transfer by atomic oxygen for atmosphere models between 120km and 220km with variable temperature gradients.

Mr. R. C. Nigam has revised the orbit of Satellite 1958 Zeta and derived values for its perigee height. Taking into account the drag coefficient and tumbling, he analyzed the acceleration of the satellite. Mr. Nigam is now investigating the oblateness of the atmosphere at an altitude equal to the perigee height of the satellite.

The orbits of the satellites listed below have been the subject of analysis during the six months ending 30 June.

1958 Alpha: Smoothed and mean elements for July and August, 1959 were published in SAO Special Report 40 (R). A revision of the orbit from launch through 30 April 1960 has been substantially completed by P. E. Zadunaisky. It will be published later in an SAO Special Report, along with a full description of the computations and analysis of the data.

1958 β1:
1958 β2: } Smoothed and mean elements were published for July and August, 1958, in SAO Special Report 40 (R), which includes numerical and graphical representations of the variations in orbital acceleration. The elements for September, 1959, through April, 1960, are being readied for publication by Mrs. B. R. Miller; they will appear in SAO Special Report No. 51.

1958 Gamma: Smoothed and mean elements covering the lifetime of the satellite were prepared for publication by Mr. Izsak. The elements and numerical and graphical representations of the changes in the acceleration are given in SAO Special Report 40 (R). These agree within the accuracy of the determination with values derived earlier by J. W. Siry for a shorter interval of time.

1959 δ2: Smoothed elements for July and August, 1959, were prepared by Dr. Kozai. The elements, numerical representation of the

DISTRIBUTION OF ORBITAL INFORMATION

The SAO distributes orbital information by telecommunications and by mail. Organizations and persons receiving telecommunications are sent all of the orbital information specified below; data distributed by mail include equatorial crossings with positional and time corrections for other latitudes, orbital elements, and modified orbital elements.

The schedule below indicates the distribution of orbital information on satellites for which SAO has primary tracking responsibility, or has tracked as backup for other agencies, or has had special interest.

The column headings under "Orbital Information" are as follows: "Baker-Nunn" indicates Baker-Nunn predictions giving precise settings for camera operation; "Equatorial crossings", equatorial crossings of the satellite in a south-north direction, with longitude and time of each crossing as well as the height of the satellite above the earth's surface at the initial crossing each day; "Orbital elements," the orbital elements of the satellite; "Modified orbital elements," the modified orbital elements and abbreviated and special-purpose forms of the elements.

Of the column headings under "Mail," the word "General" indicates general distribution to all addressees on our predictions list; "Partial," partial distribution, i.e., throughout the SAO tracking system only.

Under "Interval" are the periods during which the indicated distribution of data took place in the six months following January 1, 1960. The phrase "whole period" means that the data was distributed throughout the entire six months.

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Satellite	Orbital Information				Distribution			Interval
	Baker-Nunn	Equatorial Crossing	Orbital Elements	Modified Orbital	Telecommunication	Mail		
						General	Partial	
*1958 Alpha (Explorer I)	x	x	x	x	x	x		Whole period
*1958 β1 (rocket, Vanguard I)	x	x	x	x	x	x		Whole period
1958 β2 (Vanguard I)	x				x		x	Jan. 1-April 30
*1958 δ2 (Sputnik III)	x	x	x	x	x	x		Jan. 1-April 6
*1959 α1 (Vanguard II)	x	x	x	x	x	x		Whole period
*1959 α2 (rocket, Vanguard II)	x	x	x	x	x	x		Whole period
1959 δ2 (Explorer VI)	x				x		x	Jan. 1-April 12
*1959 Eta (Vanguard III)	x	x	x	x	x	x		Whole period
*1959 ι1 (Explorer VII)	x	x	x	x	x	x		Whole period
1960 β1 (rocket, Tiros)	x				x		x	April 1-June 5
1960 β2 (Tiros)	x			x	x		x	April 1-June 5
1960 γ2 (Transit 1B)	x				x		x	April 13-June 30
1960 Epsilon (Sputnik IV)	x				x		x	May 15-June 30
1960 Eta 2 (Greb-NRL)	x				x			June 22-June 30

*SAO has primary responsibility for tracking.

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variations of nodal period, graphical representation of the variations in orbital acceleration, and relative positions of the sun and perigee of the satellite are given for the lifetime of the satellite in SAO Special Report 40 (R). A minute-by-minute ephemeris (SAO Ephemeris Zero) giving the position and height of this satellite was prepared with elements computed by Dr. Kozai for the period 1 October 1959 to 19 March 1960. Copies of these data were shipped to scientists involved in radio ionosphere research and to the three IGY World Data Centers.

1959 α1:
1959 α2:

Smoothed and mean elements for July and August, 1959, were published in SAO Special Report 40 (R). Mr. Nigam has nearly completed his work on the orbital elements from launch through March, 1960. Accelerations and other data relating to the study of the upper atmosphere, such as relative positions of sun and perigee and the latitude of perigee, have been included in this study. The observed accelerations have been further compared with the computed accelerations. Publication of these data is expected in the fall.

1959 Eta: A study is being made of the orbit of this satellite by Dr. Zadunaisky, and the elements will be published in the late fall.

1959 Iota: Dr. Kozai has prepared a paper dealing with the orbit of this satellite during its radio lifetime from October 16 to December 3, 1959; it will be published in SAO Special Report 51.

2. Operations

During the past six months, we distributed 14,299 predictions to the twelve SAO Baker-Nunn tracking stations, and processed 13,574 observations, including 1,762 precision-reduced and 1,112 Minitrack observations.

SAO has not been given responsibility for tracking any new satellites in the past six months.

3. Equipment and Instrumentation

During the period covered by this report, the following major equipment was purchased: eight 20-drawer IBM card file cabinets; one MPA Dictet Recorder; one IBM Standard electric typewriter; six model 8N/Monroe calculators; one Fedders air-conditioner; one Bell and Howell Microfilm reader.

4. Logistics

Does not apply.

5. Personnel

During the period 21 persons joined our staff, and 3 left the program. Mr. Edward Kohn left NASA 3 to take up new duties in the NASA 2 project. As of 30 June 1960 there were 57 employees on the staff.

Dr. Hagihara, the noted Japanese astronomer, became a temporary member of the SAO staff in April. He has presented a series of lectures to Research and Analysis on "Differential Equations of Astronomical Interest," and "The Topological Approach to the Three-Body Problem." He also gave a talk at a Harvard University Colloquium on "The Gaps in the Distribution of Asteroids"; this paper will be published in the Smithsonian Contributions to Astrophysics.

Travel

January 9-15. Dr. Lautman represented the SAO at the First Interspace Science Symposium of the Committee for Space Research (COSPAR) at Nice, France.

February 1-5. Dr. Zadunaisky and Mr. Conant visited the Baker-Nunn station at Organ Pass, N. M., to familiarize themselves with field operations.

March 9-10. Dr. Lautman attended the Space Science Board Meeting of the National Academy of Sciences in Washington, D. C.

March 21-25. Dr. Whitney and Mr. Tillinghast attended a conference at the Jet Propulsion Laboratory in Pasadena, Calif. Satellite tracking problems were discussed.

April 5-8. Miss Martin and Miss Weingarten visited the Baker-Nunn station in Florida to familiarize themselves with field operations.

April 18-21. Dr. Lautman and Messrs. Conant, Izsak, Nigam, and Zadunaisky attended the meetings of the American Astronomical Society in Pittsburgh, Pa.

April 26. Mr. MacIsaac attended a meeting of the American Geophysical Union in Washington, D. C.

April 27-30. Dr. Kozai attended a meeting of the American Geophysical Union in Washington, D. C.

May 23-27. Mr. Roy Norris and Mr. J. Cherniack attended a session on automatic programming techniques at IBM in New York City.

June 10. Mr. Mechau went to Washington, D. C. to consult with Phototrack and Agiwarn personnel on the dissemination of satellite data.

June 29-30. Mr. Tillinghast attended conferences in Washington, D. C.

June 26. Mr. Nigam went to New Haven, Connecticut, to attend the Yale Summer Institute.

6. Publications

During this period, the following SAO Special Reports were published:

Special Report No. 38
Orbit Determination from Simultaneous Doppler-Shift Measurements, by I. G. Izsak

Special Report No. 39
A Variable Atmospheric-Density Model from Satellite Observations, by L. G. Jacchia

Special Report No. 40
Satellite Orbital Data
Orbital Elements for Satellite 1958 Gamma, by I. G. Izsak
Relative Positions of the Sun and Perigee of an Artificial Earth Satellite, by P. E. Zadunaisky

Special Report No. 41
Catalogue of Precise Satellite Positions, compiled under the supervision of K. Lassovsky

Special Reports Nos. 42, 43, 44
Catalogues of Satellite Observations, prepared by D. V. Mechau

Special Report No. 45
Station Coordinate Listing, prepared by D. V. Mechau

Special Report No. 46
The Effect of a Variable Scale Height on Determinations of Atmospheric Density from Satellite Accelerations, by L. G. Jacchia
Comment on the Paper Entitled Symmetry of the Earth's Figure, by C. A. Whitney

7. Future Plans

In the future development of our capabilities, the emphasis should lie in a further increase of accuracy in handling the observational material. For the practical purposes of prediction the accuracy of our present methods is very satisfactory. In final analysis, however, particularly for geodetic purposes, refinements in the collection and use of the observations would be welcomed.

To make the best possible use of the capabilities of our Baker-Nunn stations, we will improve the distribution of the observations along the orbit of a satellite by tracking before and after culmination during a longer interval of time. This is one of the reasons for the generalization of our prediction programs. The procedure of photoreduction will be improved in a corresponding manner. The oblateness perturbations will be accounted for by a second-order theory. The derivation of the effect of the sectorial harmonics of the earth potential is considered. Also, the computation of luni-solar perturbations will be included in our Differential Orbit Improvement program.

IV. PHOTOREDUCTION SECTION

Prepared by: Karoly Lassovszky
Edmund P. Bullis

1. Progress During This Period

Digitizer and keypunch units have been added to five two-screw comparators. With this equipment we can now automatically record on IBM punch cards the measurements of the x and y axes of the images of satellites and reference stars. The cards are then used directly in the automatic reduction program on the IBM-704 electronic computer. We are processing each month more than 800 precision positions, with atomic (A_1) time indicated.

A total of 547 satellite positions with final times was published in SAO Special Report No. 41.

With the assistance of four temporary employees, we are continuing our project of marking the star charts with catalogue numbers in the southern declination.

The Film Evaluation unit is routinely reporting the results of their assessments to the satellite optical tracking stations. This procedure is improving the quality of film output.

Phototime is being successfully reduced to atomic (A_1) time for films from all twelve tracking stations.

We have made several refinements to the automatic reduction program of the IBM-704 computer. Input data are now sorted automatically rather than by hand.

2. Operations

More than 6400 films were received from the tracking stations during this period; of these, more than 4800 contained satellite images from which rough field positions had been determined. We evaluated more than 3100 of these films, and found 2811 images measurable to the precision required. Analysis of the reasons for rejection of films indicates a high correlation between camera focus and faintness of the image, and between poor film processing and faintness of the image. The Tracking Stations section has taken steps to remedy these and similar faults.

Unsuccessful films, i.e., films on which station personnel have been unable to find a satellite image, are no longer shipped to Cambridge but are retained at the stations.

During the period of this report, 3138 precision satellite positions with atomic (A_1) time were determined.

3. Equipment and Instrumentation

The Mann comparator with a monocular viewing system is being modified so that the monocular system will be interchangeable with a projection system.

We have received blueprint racks on which to hang star charts; these simplify the problem of handling the charts.

The BD and CD star charts have been reduced to the scale of the tracking station films and have been printed on transparent plastic so that they can be used for the identification of reference stars. Some out-of-print star catalogues have been photocopied, and the copies have been bound. Additional copies of the AGK_2 and Yale catalogues have been received.

Four room air-conditioners, and a Friden desk calculator that automatically extracts square roots have been ordered.

We have negotiated a one-year contract with the Benson-Lehner Corporation to service the digitizers.

4. Logistics

Does not apply.

5. Personnel

Mr. Alvin Goldstein and Mr. Edwin B. Weston visited the New Mexico tracking station January 3 through January 15 to discuss techniques of photoreduction.

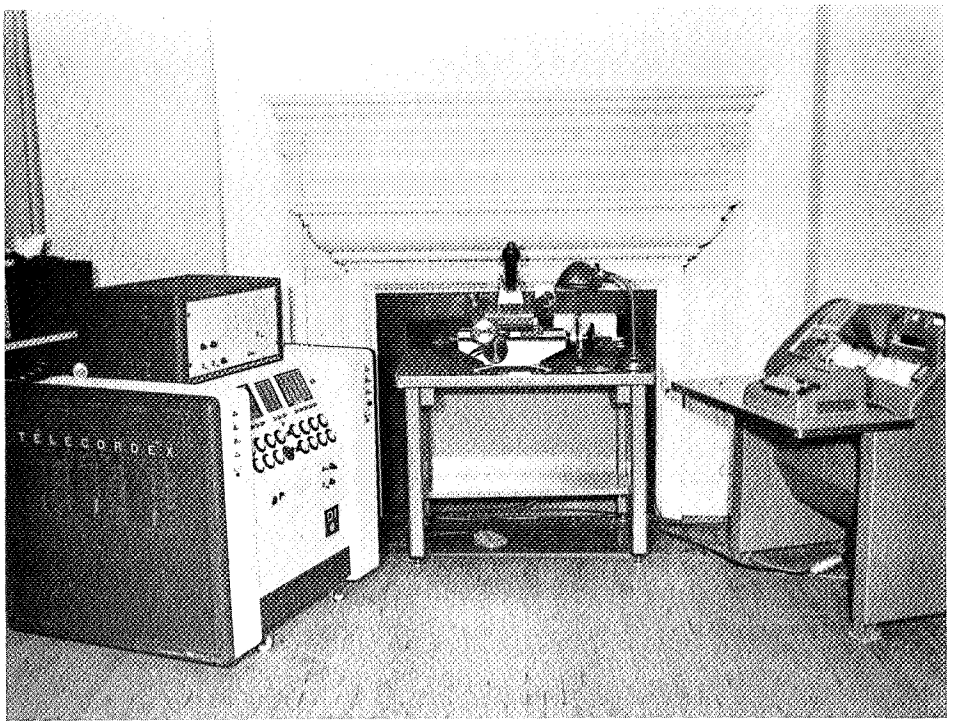
Mr. Edmund P. Bullis visited Washington, D. C., April 8 through 11 to confer with Telecordex users in the Washington area.

In May Mr. Weston visited observatories and manufacturers in Michigan, Indiana, British Columbia, Ontario, California, Minnesota, Wisconsin, Illinois and New York, to investigate different types of self-recording microphotometers.

As of June 30, 1960, the staff of the Photoreduction Section consisted of 43 regular and 4 temporary employees.

6. Publication

A total of 547 precision satellite positions with final time was published in SAO Special Report No. 41. Included were positions for the following satellites:



Digitizer, two-screw comparator, and key punch units in photoreduction

Surveying a SPOT film

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Satellite	Number of Positions
1958 α1	82
1958 β1	3
1958 β2	19
1958 δ1	29
1958 δ2	74
1958 Zeta	11
1959 α1	265
1959 Eta	64
Total	547

The Report also included several papers concerning the methods of reducing the satellite positions.

7. Future Plans

A new automatic reduction program is being written. It will include not only the determination of position but also the reduction of time. It will later incorporate the star catalogues, so that reference stars can be automatically identified.

We are considering the possibility of purchasing a self-recording microphotometer; the instrument would be used to investigate the photometric applications of satellite images.

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V. COMMUNICATIONS

Prepared by: Charles M. Peterson

1. Progress During This Period

Two joint communications meetings were held by members of SAO, NASA, and SPACETRACK on April 19 and May 18, 1960. As a result, steps have been taken to eliminate the duplicate transmission of satellite information by electric means to the same addresses. These groups exchanged teletype distribution lists and agreed upon areas of responsibility. We have made considerable progress in this direction, with the full problem being resolved in July.

In conformance with procedures for sending unclassified messages over military circuits, we are now using the abbreviation UNCLAS within the Smithsonian satellite tracking program. This abbreviation appears as the first word in the text of the message, and is followed by one of these coded labels:

SATPRED:	satellite predictions
SATCROS:	satellite equatorial crossings
SATORB:	satellite orbital elements
SATOBS:	satellite observations
SATMOD:	satellite modified orbital elements.

These labels conform to the policy of CNO (Chief of Naval Operations) of identifying unclassified messages in a semi-coded form.

2. Operations

During this period, the Communications Center handled a monthly average of 500,000 words (5 characters per word), of which 60 percent were outgoing messages. Approximately 90 percent of all messages contained satellite observations, predictions, and orbital elements.

3. Equipment and Instrumentation

The Olivetti teletype tape-cutting machine was removed on April 30, 1960. The machine did not meet our requirements for high-speed tape preparation.

A teletype reperforator was installed on June 1, 1960 to tie in with the Western Union Domestic machine. This combination eliminates the need for repunching observations that are received over this line and thus speeds both internal processing and the transfer to NASA and SPACETRACK.

4. Logistics

Does not apply.

5. Personnel

Mrs. Beatrice Vitale was appointed telephone switchboard operator on a part-time basis, beginning January 28, 1960.

Miss Joan Long ended her services as Communications Secretary on April 29, 1960.

Mrs. Gail McDonough was appointed Secretary on May 16, 1960.

Mr. Charles M. Peterson, Chief of Communications, was appointed Classified Control Officer for the Communications and for the Computations, Research and Analysis divisions of the SAO.

6. Publications

Does not apply.

7. Future Plans

By renting two teletype tape-cutting machines from Western Union, we will obtain more flexibility in tape preparation and will be able to speed the transmission of complicated information containing figures in tabulated form.

We plan to resurvey the present SAO teletype distribution lists and to eliminate names for whom mail distribution will suffice.

SAO communications center